

2013 Motor Diagnostics And Motor Health Study



Researcher: Howard W Penrose, Ph.D., CMRP

An Electrical Motor Diagnostics Study Sponsored By



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EXECUTIVE SUMMARY

The first Motor Diagnostics and Motor Health Study (MDMH) was published in 2003 as a collaborative work between SUCCESS by DESIGN Publishing, NetExpressUSA and BJM Corp. Ten years later an update to the study has been performed by SUCCESS by DESIGN Publishing in order to determine how the industry has advanced in a decade as well as to explore independent information on Electrical Motor Diagnostics (EMD).

The number of respondents as well as the types of industries they represent are similar to the 2003 MDMH in 2013 and a number of respondents were included in the 2003 study. The result is that the study should represent changes within the industry as technology and know-how also changes and a new generation of reliability, maintenance and management enter industry. The information used to create the introduction for the 2003 study has not been updated in the past decade; however, there have been significant issues within the economy that had occurred since 2008 until after 2010 and, it is argued, still occurring. How has industry in the area of motor diagnostics and motor health reacted to these issues? Have financial conditions set back motor system reliability? With the known importance of rotating machines to the livelihood of manufacturing, industry and commercial enterprises, what has changed to improve or decrease reliability?

The good news for those involved in motor diagnostics and motor health is that those using some form of testing on their machines has increased from 68% in 2003 to 85% in 2013. This represents a significant increase in attention to this important area. There have been some changes, such as the top three methods used for evaluating electric motors went from insulation resistance followed by visual inspections followed by multimeters in 2003 to visual inspections, insulation resistance followed by vibration analysis in 2013. Vibration analysis and insulation resistance remain within the top three methods for electric motor PdM tests with the one major change being the third place changed from visual inspections to Motor Circuit Analysis (MCA – specialized off-line testing).

Another major change that occurred since 2003 is the acceptance of additional testing within the Institute of Electrical and Electronics Engineers, Inc. (IEEE) through the IEEE 1415-2006, “IEEE Guide for Induction Machinery Maintenance Testing and Failure Analysis.” The standard reviews many existing testing methodologies plus troubleshooting processes related to induction motors. In 2003, the Electric Power Research Institute, Inc. (EPRI) performed research on motor diagnostic technologies and published the results concurrent with the original MDMH study in May, 2003, as the “Advanced Electric Motor Predictive Maintenance Project,” or AEMPM. Both the standard and study provide significant guidance in the use and application of EMD technologies and the importance of electric motor reliability.

Another change since 2003 is that the number of respondents that use insulation resistance testing went up by 10% from 69% to 79% and the number using MCA increased from 19% to 42%. The number of respondents reviewing the implementation of MCA dropped from 37% to 30%; however, we feel the reason has more to do with many of the companies that were reviewing the application of the technology have now applied it. The issues preventing the application of EMD for any reason remain similar with the

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top three reasons being learning curve, cost and manpower issues. At the same time, 68% of companies in 2003 and 66% of companies in 2013 support training programs for their personnel applying these technologies.

The number of critical motors remained 50-100 with the types of motors reported being three phase, DC and then single phase motors in 2003 are now reported as 92.5% three phase, 62.3% single phase and 58.5% DC motors. The majority of facilities that had an aggressive program have motors up through 5000 horsepower, which has also remained the same.

A significant change has shown since 2003. In 2003, the primary group responsible for electric motors were the electricians (56%) with only 2% of reliability engineers holding that responsibility. In 2013, reliability engineers and predictive maintenance teams hold 43% of the responsibility and electricians have dropped to 26%. Could this change be a result of companies realizing that a more concerted effort in electric motor and predictive maintenance would be needed to improve competitiveness? A serious question that will be explored in the data.

In 2003, 54% of companies had a motor reliability or PdM program in place which has increased 14% to 68% of companies having applied such a program. The average downtime costs remains at \$10,000 per hour as does the average plant claimed operating profile of 24/7. The majority of planned shutdowns for maintenance remain annual.

The types of EMD have made some changes between 2003 and 2013. In 2003, offline MCA was 14%, online (Electrical Signature Analysis (ESA) and Motor Current Signature Analysis (MCSA)) was 16% and those using both was 70%. In 2013, MCA was 11%, ESA alone was 4%, use of both was 76% and 11% dropped the use of the technology. In 2003, 45% saw a Return On Investment (ROI) using EMD while 47% had a good ROI, 8% did not see a good ROI and 45% were unable to answer.

The perception of what MCA could be used for has not changed from 2003 to 2013 with PdM of the windings, troubleshooting and rotor testing remaining the top three. While the perception of ESA/MCSA changed slightly from PdM, windings and troubleshooting to rotor, windings and PdM across the decade.

With all of the attention to energy and environment, especially during the 2013 survey, it was expected that energy would be a prime driver for a motors program. In 2003, energy was 3% of the response, all from outside the United States, and it dropped to a solid 0% in 2013. The prime driver was reliability at 70% in 2003, which has increased to 75% in 2013.

ELECTRIC MOTOR RELIABILITY STUDIES

One of the most frequently quoted studies related to electric motor reliability is a 1983 Electric Power Research Institute (EPRI) project performed by General Electric(1). It has been used to support a variety of programs, equipment, and other electric motor strategies. In fact, this author has cited other papers that referenced the study over many years and had been searching for a copy of the original in order to provide additional detail. Recently, the paper that covers the details of the study has been made available through the Institute of Electrical and Electronics Engineers, Inc. (IEEE) and a review quickly identifies that many of the statements attributed to the study are either incomplete or outright incorrect.

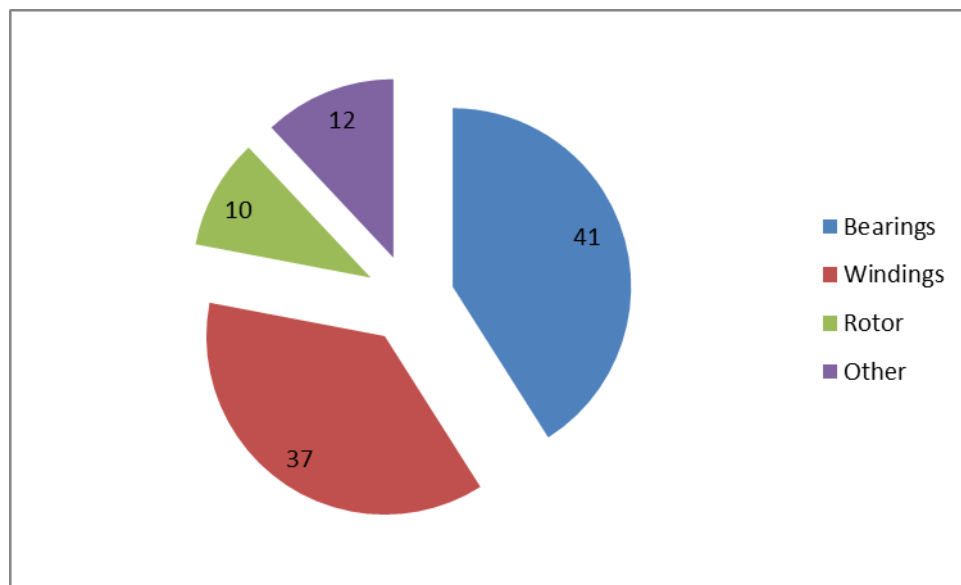


FIGURE 1: 1983 EPRI STUDY FAILURE RATES(1)

The good news is that this was not the only study on electrical and electric machine reliability. Studies had been performed by several groups, including an IEEE Power Engineering Society group, since 1962 all the way through 1995, and then supported by other industry groups as late as 2010. What is particularly interesting about these studies is that they focus on different industries, such as utilities, petro-chemical, general industry, and commercial buildings, yet have very similar results. While each study looked deeper into the issues, and the results were different than represented by many papers and books, the actual findings were much more interesting and far more supportive of the programs and strategies presented in those cases.

In this article we are going to review what these studies really represent in relation to larger machines, which was the primary purpose of many of the papers. This includes the identification of the reliability issues that were identified and the recommended strategies with supporting information. While the full breadth of the related studies is far more than we can cover in this article, the information that will be discussed will have a significant impact on how you look at your motor system.

A LITTLE ABOUT THE EPRI STUDY

The percentages shown in Figure 1 have often been cited as the conclusion of the EPRI study, which is correct. However, the details behind those percentages are also very interesting. This includes the number of motors that failed more than once and the apparent causes of those failures as well as the general reliability of electric motors in utilities.

First it was noted that more than 90% of the failures occurred in 54% of the facilities evaluated and half of the failures occurred in 17% of the facilities. This means that a majority of the failures occurred in less than half of the facilities evaluated. Overall, the reliability of the motors across all of the facilities was 3.4% per motor per year with some facilities having an obviously higher failure rate and 46% of facilities having a very low failure rate. In all, the study found that the plants with the higher failures had a failure rate of 9.3% per year (17% of facilities) and the 13% of facilities had about a 0.8% failure rate.

There were 4797 motors evaluated in the study with a total of 1227 failures on a total of 872 motors that failed. This means that 335 of the 1227 failures were repeat failures. The best facilities saw some of the motors fail two to three times versus the median group which saw a number of failures through four or more times and the worst group that saw an even higher repeat failure rate.

The apparent causes of failure were also surprising with only 34.1% of failures being from misapplication and misoperation. However, it was noted that more than half (50.2%) of the failures were not specified with an apparent cause. The failure modes were correctly identified with the repeated failures being the same as the original failures. Table 1 identifies the failures and the percent of each failure mode.

TABLE 1: FAILURE MODES (1)

Failure Mode	Number of Motors	Percent of Total (%)
Other – Unspecified	313	35.9
Insulation to Ground	161	18.5
Sleeve Bearing	85	9.7
Ball Bearing	43	4.9
Thrust Bearing Vertical	41	4.7
Oil Leakage	36	4.1
Turn Insulation (Short)	32	3.7
Rotor Bar Failure	31	3.5

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Roller Bearing	20	2.3
Bearing Seal	20	2.3
Loose Blocking	16	1.8
Rotor Shaft	13	1.5
Oil System	12	1.4
Stator Slot Wedges	11	1.3
Loose Iron	9	1.0
Stator Frame	7	0.8
Line Cable	6	0.8
Coil Connection	5	0.6
Balance Weights	5	0.6
Accessories	4	0.5
Thrust Bearing Horizontal	2	0.2

Of these failures, design was determined to be 39.1% and workmanship was 26.8%. In effect, the survey determined that 65.9% of the motor failures were related to the manufacturer and rebuilder.

The failure rate by manufacturer was found to range from 0.84% to 5.27% for the top seven manufacturers, 16.44% for one manufacturer, and a combined total of 6.50% for all other manufacturers. The manufacturers were not identified.

One of the issues brought to light by the statistics in the EPRI study is that insulation to ground faults are the majority of winding faults. Quotes related to this study and other industry statements identify turn faults as the initiation of failure. However, that statement is not found in the reports in this or the follow-up studies.

REVIEW AND COMPARISON OF STUDIES

In the 1980s motor failure studies it was determined that a given population of motors had either an average failure rate of 0.0708 Failures per Unit per Year (FPU) for general industry(2) and 0.035 FPU for

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maintenance intensive industries such as utilities(1). In 1995, new studies would support the original assumptions. These industry studies found that machines with required minimum protection, such as fuses or breakers, the failure rate was 0.0707 FPU, while those with embedded thermal protection had a failure rate of 0.0202 FPU, or less than 1/3rd of the failures(3).

Maintenance was also found to have a significant impact through all of the studies. When maintenance frequency was involved, the post-EPRI studies all found that frequencies under a year had the best impact. The 1985 IEEE study identified that maintenance performed with a frequency under 12 months resulted in 0.0124 FPU, from 13 to 24 months 0.0506 FPU, and greater than 25 months 0.0881 FPU. Machines that were maintained within the 12 month period were also found, within the survey, to have excellent practices resulting in the failure rate of 0.0124 FPU while all others had failure rates in excess of 0.0681 FPU.

A key difference between the EPRI and IEEE studies, the IEEE 1985 study reviewed not just the general failures, but also broke out service factor, speed, and maintenance. The IEEE 1995 study further modified the findings by identifying size and voltage in order to determine factors that relate to each. In 2010, a paper on root cause failure analysis supported the findings of the 1995 study(4).

One consideration for these studies are their ages. With the first study published in 1974 relating to electrical reliability of electrical equipment in industrial plants through to the 1995 study, fundamental facts had not changed. The reliability of machines based upon application, enclosure, service factor, speed, protection, and level and type of maintenance. The combined studies covered virtually all industries from petrochemical and chemical to utilities, to commercial and industrial applications.

APPLICATION OF STUDIES TO LARGE MACHINES

As the studies provided similar data based upon failure rates, and it can be assumed that the variations in failure rates and reliability of machines by facility in the EPRI study relate to the level of maintenance, we will focus on the information in the IEEE studies. This information is broken down by size, enclosure and speed, providing the ability to demonstrate the importance of maintenance on large machines.

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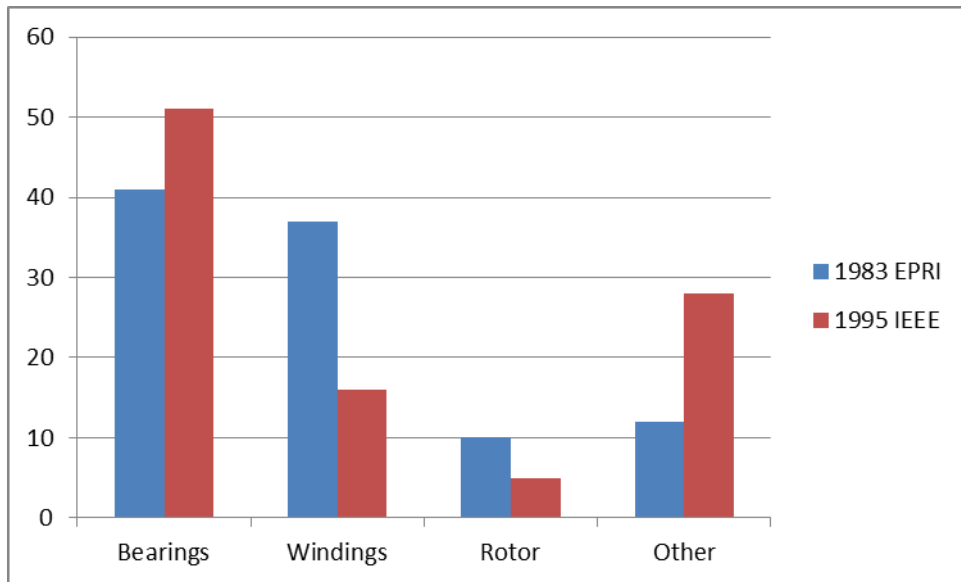


FIGURE 2: COMPARISON OF 1983 EPRI TO 1995 IEEE SURVEY(1), (3)

The primary difference is identified in Figure 2 where the various faults found in the machines were significantly different. It is noted that the EPRI study focused on utility motors 100 horsepower and larger while the IEEE study related to machines of 10kW (~15hp) and larger at 50 Hz and 60 Hz.

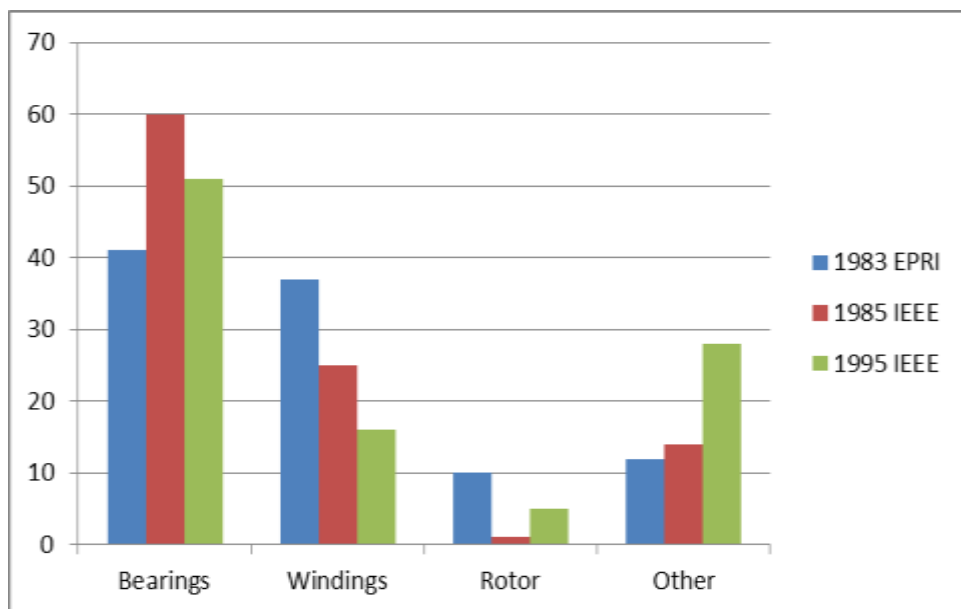


FIGURE 3: COMPARISON OF THE 1983 EPRI AND THE 1985 AND 1995 IEEE SURVEYS(1), (2), (3)

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As shown in Figure 3, the actual failure modes for each industry group were significantly different other than a similar pattern. A majority of faults was bearings, windings second, then the rotor, then all other faults combined. The 1985 IEEE survey covered industrial and commercial facilities while the 1983 EPRI study covered utilities only and the 1995 IEEE survey covered petro-chemical and similar industries. Other significant differences with the 1985 survey is that it covered machines from 200 horsepower to 10,000 horsepower, voltages to 13.8kV, and induction, synchronous, wound rotor and DC motors.

Based upon the breadth of industries covered, we will review the following data as it relates to the 1985 IEEE survey and machines over 1,000 Volts. From an overall industry standpoint, 2300 and 4160 Vac machines have a median failure rate of: 0.0714 FPU for induction motors; 0.0762 FPU for synchronous motors; and, 0.0319 FPU for wound rotor motors.

If we further break down the information from the survey, motors from 500 to 5000 horsepower had a median failure rate of 0.0730 FPU and from 5001 to 10,000 horsepower a median failure rate of 0.2169 FPU. In relation to motor speed and failure rate: 0-720 RPM is 0.1004 FPU; from 721-1800 RPM is 0.0721 FPU; and 1801-3600 RPM is 0.0519 FPU. In effect, larger, slower speed motors have a higher failure rate with most machines being induction and synchronous motors in the survey. The wound rotor machines covered tended to be a smaller horsepower.

Based upon the IEEE studies, the use of continuous monitoring, such as temperature and vibration, can reduce the failure rate by about 1/3rd. None of the studies has identified the effect of the use of partial discharge testing on machines over 6,000 Volts. However, it can be assumed that such practices and technologies are used for fault detection rather than winding protection, in most cases. Does this have an impact?

The IEEE studies identify the number of faults that are detected by a variety of technologies and maintenance practices and the median downtime hours per failure based upon the fault being detected as part of a maintenance practice or during operation. According the 1985 IEEE survey the failures were detected as found in Figure 4.

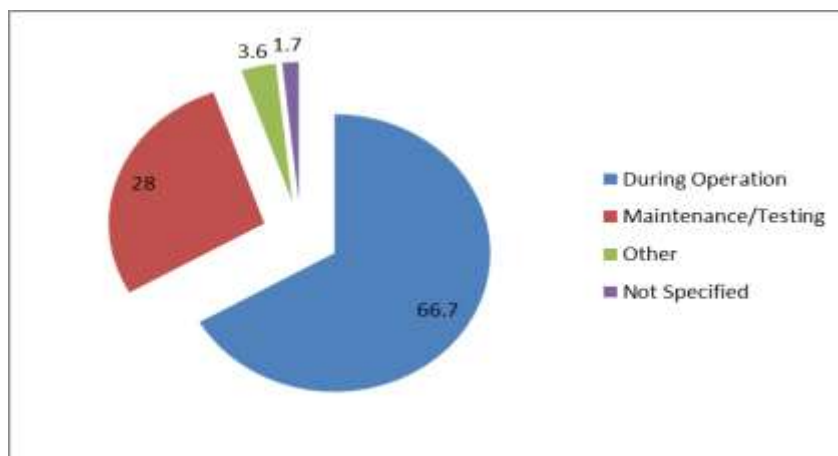


FIGURE 4: TIME FAILURES DISCOVERED(2)

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The level of maintenance program and frequency of maintenance practices also had a significant impact on not just the failure rate, but also the median hours downtime per failure (Table 2).

TABLE 2: : MAINTENANCE VS. FAILURE RATE(2)

Level of Maintenance and Frequency	Failure Rate (FPU)	Median Hours Downtime/Failure (Impact on Production)
Excellent, <12 Months	0.1115	8
Excellent, 12-24 Months	0.0364	24
Excellent, >24 Months	0.0315	36
Excellent, Average	0.0708	16
Fair, <12 Months	0.0872	16
Fair, 12-24 Months	0.0403	54
Fair, >24 Months	0.0719	165
Fair, Average	0.0710	16
Poor, 12-24 Months (All)	0.0563	96

The maintenance practices that encompassed 'excellent' maintenance included:

- Visual inspections;
- Insulation resistance;
- Cleaning;
- Lubrication and/or filters;
- Vibration analysis;
- Bearing check/inspection;
- Ampere and temperature tracking;
- Air gap checks;
- Alignment; and,
- Check/change brushes, as applicable.

One of the explanations for the higher failure rate and the lower associated production average disruption is was that potential faults were detected as part of the maintenance practice.

CONCLUSION

Past electric motor studies have been incorrectly quoted for many years. A review of the associated studies identified that the actual opportunities are far greater than have been identified. The purpose of this paper was to demonstrate some of the information in relation to large, medium voltage machines. Primary opportunities include the use of continuous monitoring systems, such as temperature and vibration, and the application of technologies and maintenance practices that will avoid or detect electrical and mechanical faults. The result is both a reduction in failure rate by about 1/3rd and significant reduction in production downtime.

While the studies have been performed and published from 1973 through 1995, the information on failure rates remained similar through this period and papers published as late as 2010 continue to support the original findings. The primary differences between the studies are the target industries and the failure modes listed by each study.

BIBLIOGRAPHY

(1)Albrecht, et.al., "Assessment of the Reliability of Motors in Utility Applications," IEEE Transactions on Energy Conversion, Vol. EC-2, No. 3, September 1987

Albrecht, et.al., "Assessment of the Reliability of Motors in Utility Applications - Updated," IEEE Transactions on Energy Conversion, Vol. EC-1, No. 1, March 1986

(2)"Report of Large Motor Reliability Survey of Industrial and Commercial Installations, Part I" IEEE Transactions on Industry Applications, Vol. IA-21, No. 4, July/August 1985

"Report of Large Motor Reliability Survey of Industrial and Commercial Installations, Part II" IEEE Transactions on Industry Applications, Vol. IA-21, No. 4, July/August 1985

"Report of Large Motor Reliability Survey of Industrial and Commercial Installations, Part III" IEEE Transactions on Industry Applications, Vol. IA-23, No. 1, January/February 1987

(3)Thorsen and Dalva, "A Survey of Faults on Induction Motors in Offshore Oil Industry, Petrochemical Industry, Gas Terminals, and Oil Refineries," IEEE Transactions on Industry Applications, Vol. 31, No. 5, September/October 1995

(4)Bonnett, Austin H., "Root Cause Failure Analysis for AC Induction Motors in the Petroleum and Chemical Industry," Proceedings, 57th Annual Petroleum and Chemical Industry Conference, 2010

MDMH SURVEY

The survey portion of the study consisted of 30 questions. These were made up of the same questions asked in the original 2003 survey plus several added that are directly related to the application of Electrical Motor Diagnostics (EMD) and equipment. Many of the questions were left 'open,' giving the respondent the ability to add additional information. In this section, we will discuss each of the questions, responses, plus drill down into the answers given in order to determine the significance of motor diagnostics and motor health in all sectors.

RESULTS OF THE MDMH SURVEY

Are you presently using some form of testing on your electric motors?

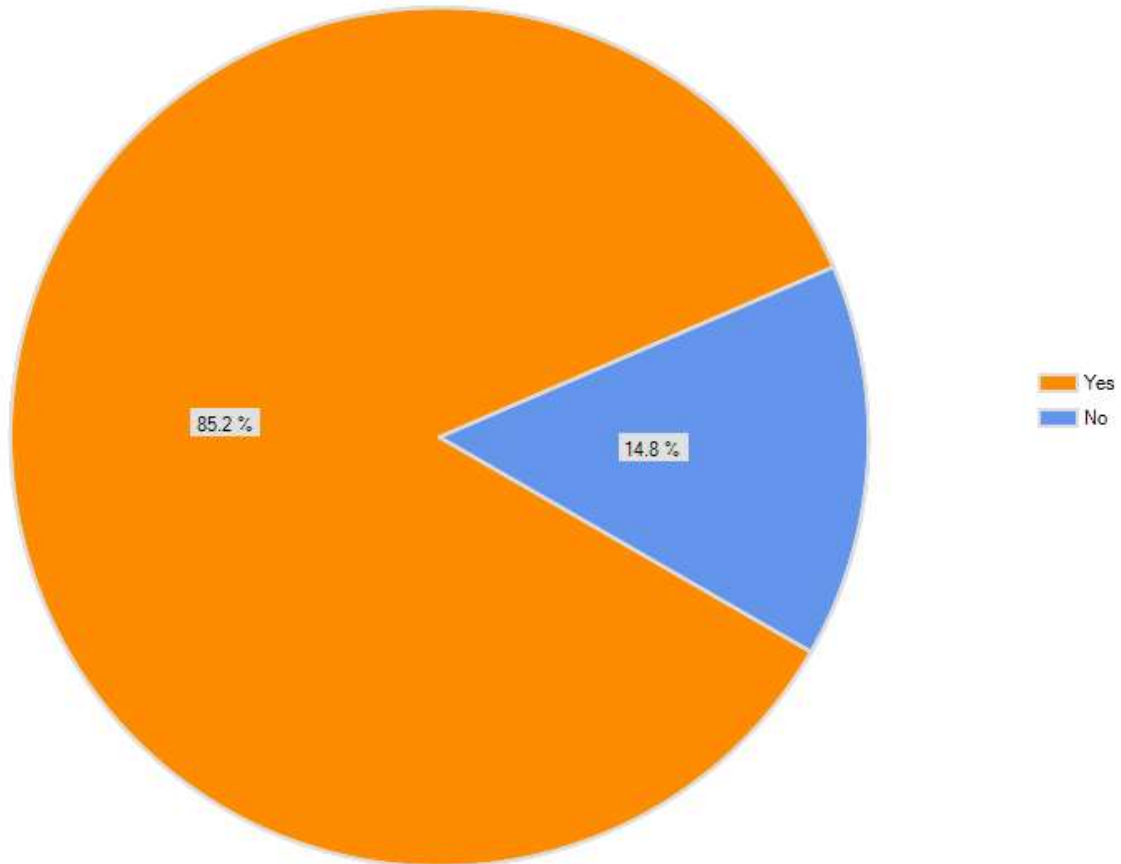


FIGURE 5: USING SOME FORM OF TESTING MOTORS

As shown in Figure 5, 85.2% of the respondents identified that they are using some form of testing on their electric motors while 14.8% said they were not. When we take a closer look at those responding that they are not using some form of testing, technologies and inspections, including visual, are still identified. The types of companies that provided a negative response range from commercial buildings to aircraft and automotive manufacturers.

Contrary to the 2003 study, it appears that 100% of the respondents are performing some kind of testing, or have the testing available. In this case, one of the negative respondents stated that the testing of motors was effective, the others identified the lack of testing due to manpower, cost, training and other factors.

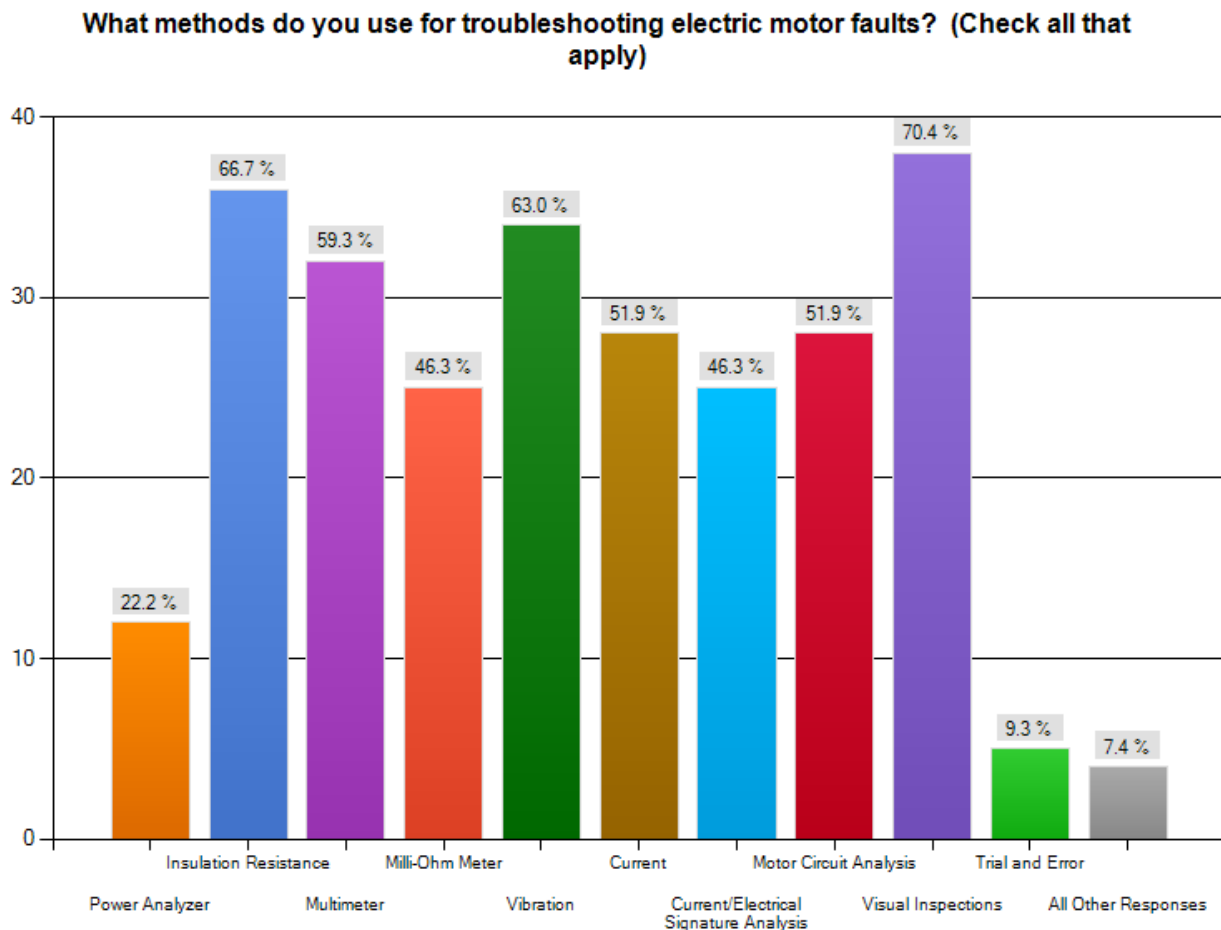


FIGURE 6: METHODS FOR TROUBLESHOOTING

The next question, as shown in Figure 6, relates to troubleshooting electric motors. The top three methods identified were visual inspections (70.4%) followed by insulation resistance (66.7%) and vibration (62.3%). This is an interesting response as the EPRI and IEEE studies cited in the last chapter identify that mechanical and bearing faults are the most prevalent. In fact, of the remaining answers, a majority of responses were electrical in nature with the lesser accepted being mechanical in nature. It was noted that both MCA (51.9%) and ESA/MCSA (46.3%) technologies were included and on the rise, up from not being mentioned in the 2003 study.

One response included torque tests, partial discharge and tan delta testing, representing less than 1%.

The number one method for trending the condition of electric motors is vibration followed by insulation resistance and then MCA. Thermography and polarization index are a tied close fourth. Additional entries included partial discharge and tan delta testing, representing less than 1% each. Several 'additional' responses included technology brand names. Adding those to the appropriate locations has no impact on the results representing less than 1%, as well.

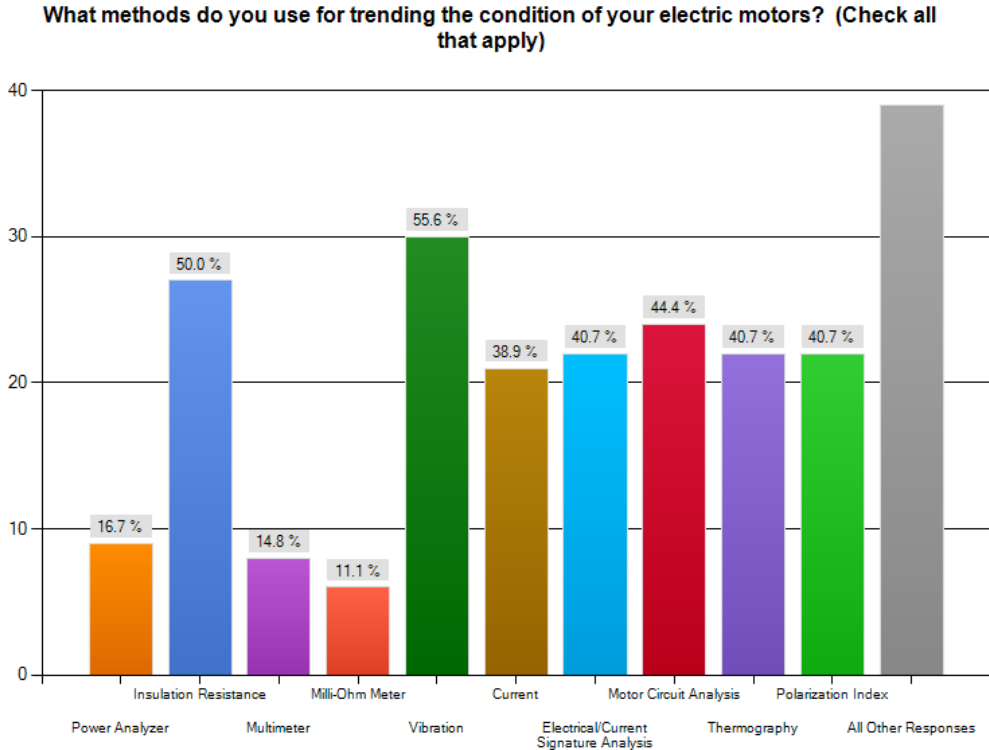


FIGURE 7: METHODS FOR TRENDING

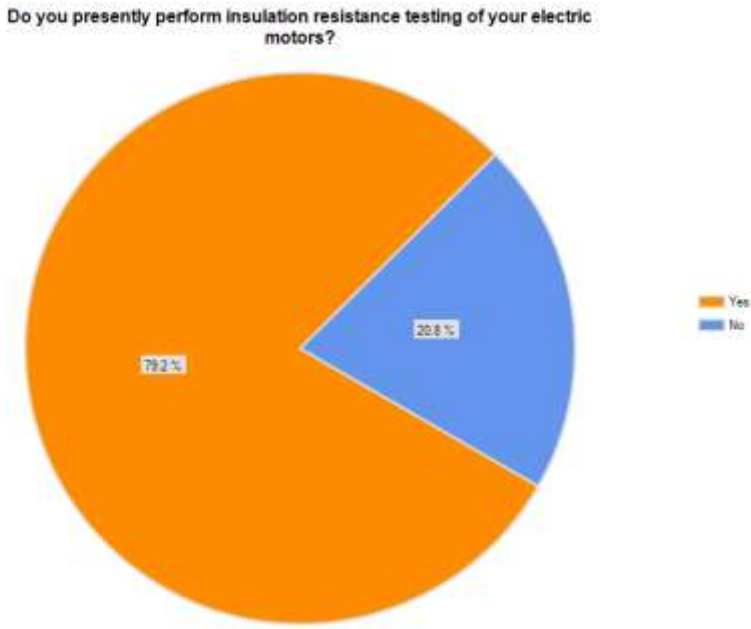


FIGURE 8: PERFORM INSULATION RESISTANCE

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79.2% of respondents stated that they presently perform insulation resistance testing of motors. Several of the respondents commented that they do use insulation resistance testing, just not for PdM programs.

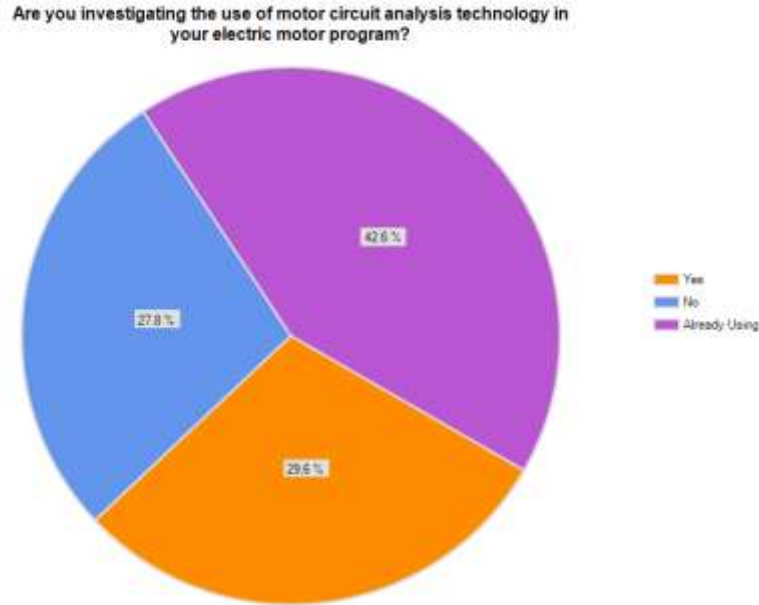


FIGURE 9: INVESTIGATING MCA

In 2003, there was limited use of MCA testing within industry. While the number of companies investigating the application of MCA has dropped, the number of respondents using has jumped to 42.6%. This represents that in the last decade off-line testing technology applications have increased significantly.

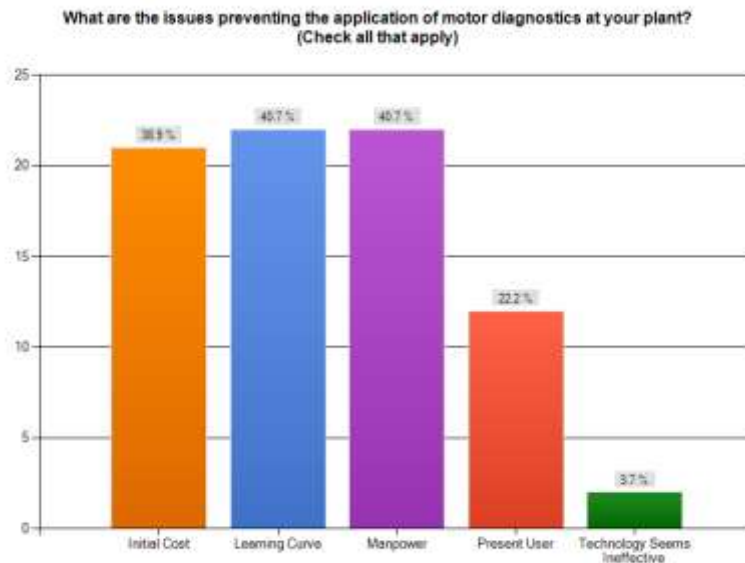


FIGURE 10: ISSUES PREVENTING EMD

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The primary issues blocking the application of motor diagnostics appear to be evenly split between learning curve, manpower and initial cost. The issue appears to span across all industries. Additional comments included safety (NFPA 70E, in particular) when it comes to online testing and the costs associated with the special jacks available for ESA/MCSA devices.

The next question was related to the view of motor diagnostics and how it has changed over the past ten years. Following are paraphrases of the responses:

- ⤴ Difficult to trend due to manpower and equipment limitations
- ⤴ Improved MTBF (in one case noted to 14 years)
- ⤴ More widely accepted by customers (several service company responses)
- ⤴ Used to monitor equipment in aging plants
- ⤴ Allows to test new and repair motors. Used to determine if manufacturer or repair is following standards
- ⤴ Has proven effective and value
- ⤴ Improves ability to forecast maintenance budgets

Negative through neutral responses represented less than 25%. Of the positive responses, many refer to measures used. When the overall study data is reviewed, it becomes apparent that those organizations keeping a scorecard are faring generally better, especially in management support, than those who are not.

Does your company sponsor training for predictive and preventive maintenance technologies?

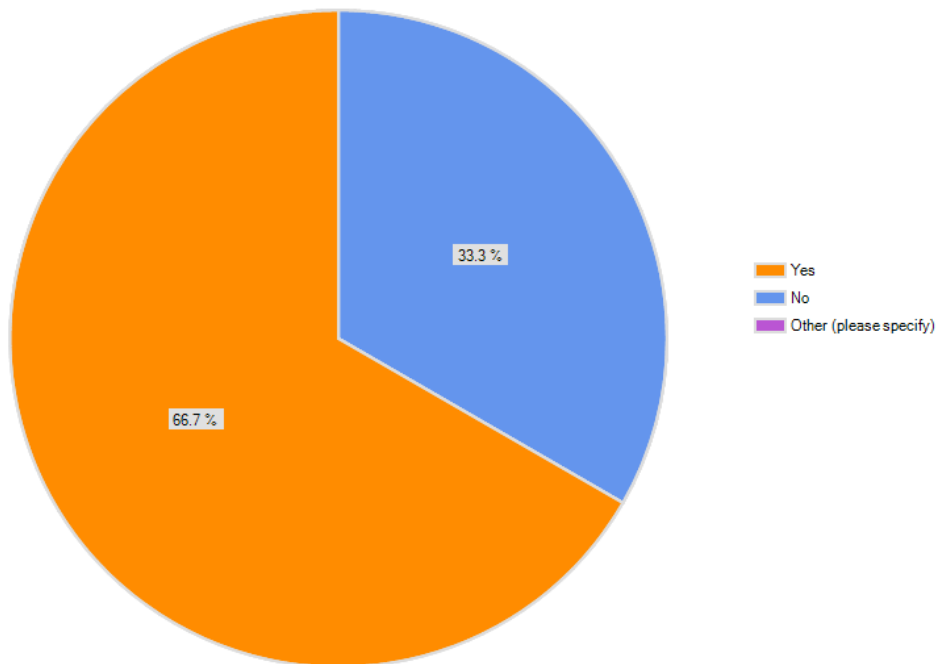


FIGURE 11: COMPANY SPONSOR PDM/PM

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Of the companies that sponsor training for PdM and preventive maintenance technologies, a majority were identified as having successful programs.

The types of plants represented in this study included:

- ^ Municipalities and Utilities
- ^ Automotive
- ^ Motor repair and services
- ^ Motor manufacturing
- ^ Oil and Gas
- ^ Fertilizer
- ^ Nuclear power
- ^ Power generation
- ^ Steel and Primary Metals
- ^ Commercial facilities, including schools
- ^ Plastics
- ^ Aircraft manufacturer
- ^ Paper
- ^ Chemicals
- ^ General Manufacturing
- ^ Consultants
- ^ Machine tool manufacturer
- ^ Printing
- ^ Military/Government

More than one of each of the above were represented with the addition of repair shops and motor manufacturers over the 2003 study, which did not include either. The number of service companies providing motor diagnostics as a service definitely appears to have had an impact as 18.5% of the respondents were repair and service. It is also noted that a larger portion of respondents were from the United States; however, as found in the 2003 MDMH study, most of the issues remain very similar in relation to electric motors.

In general, the number of critical motors for the respondents have not changed significantly since 2003 with 50-100 critical motors being the average.

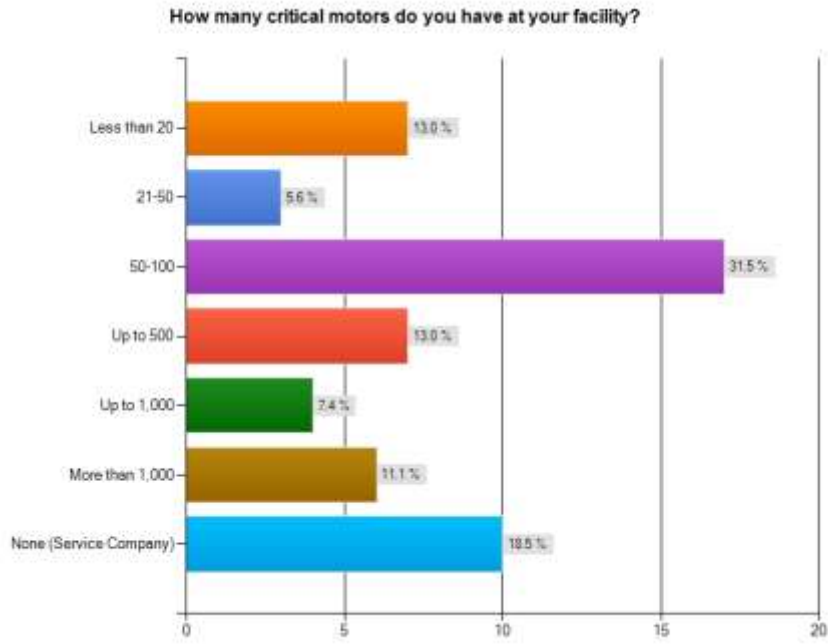


FIGURE 12: NUMBER OF CRITICAL MOTORS

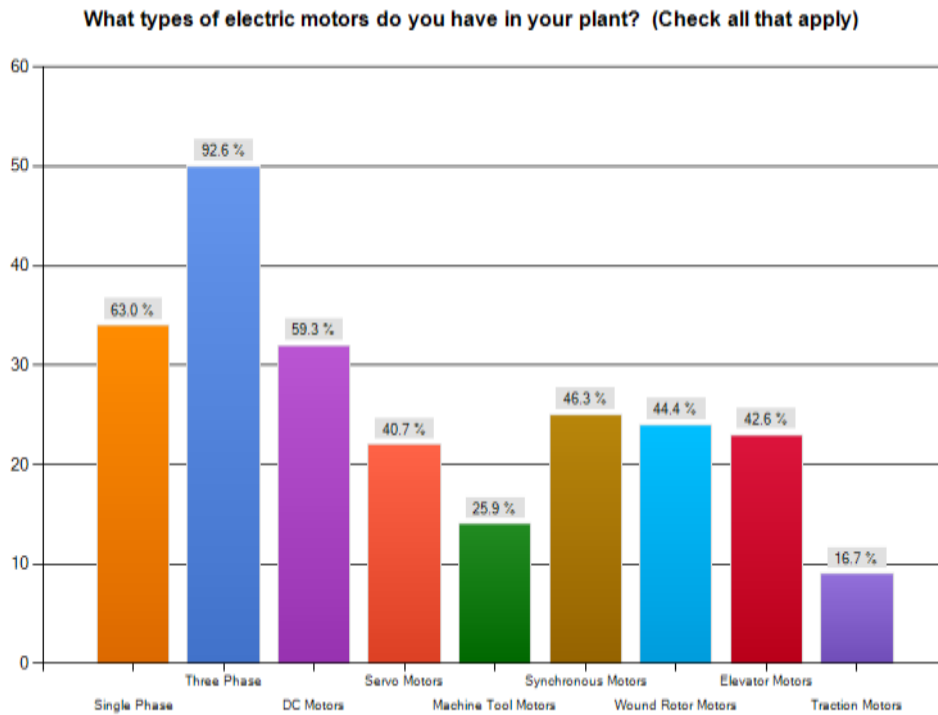


FIGURE 13: TYPES OF MOTORS

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Single and three phase motors were still at the top. Surprisingly, DC motors remain a significant force within industry. One issue that exists in relation to DC motors and generators is the lack of standards available that cover their maintenance and application. Servo and machine tool motors remain a significant factor within North America, as well as the rest of the world. Wound rotor, synchronous and traction motors, some of which were identified as vehicle motors – a new addition, averaged in the high 30% each.

While the total number of respondents had motors less than 1000 horsepower, a surprising number had motors up through 5000 horsepower. A number reported machines well over 5000 horsepower in comments which resulted in an even split of facilities that had motors under 1000 horsepower and above 1000 horsepower. Service companies reported none.

There were a number of responses of 'none' in comments related to additional wound equipment at each plant. The difference between the 11% not having transformers and the others reporting 'none' resulted in the same number as the service companies.

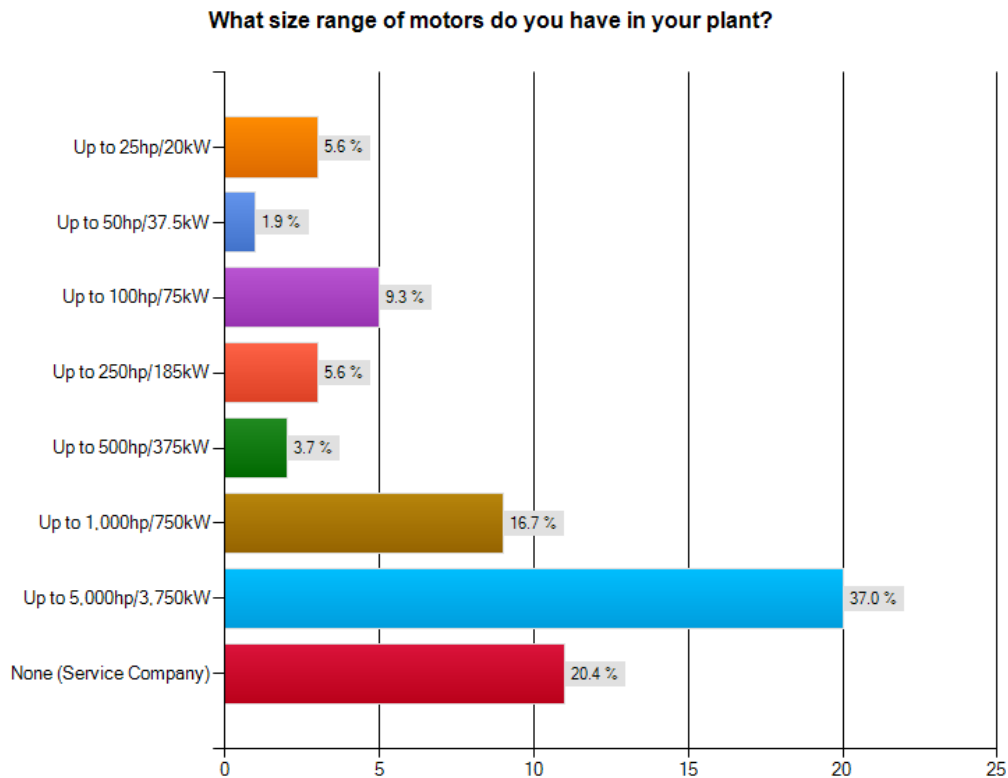


FIGURE 14: SIZE RANGE OF MOTORS

Are you presently using some form of testing on your electric motors?

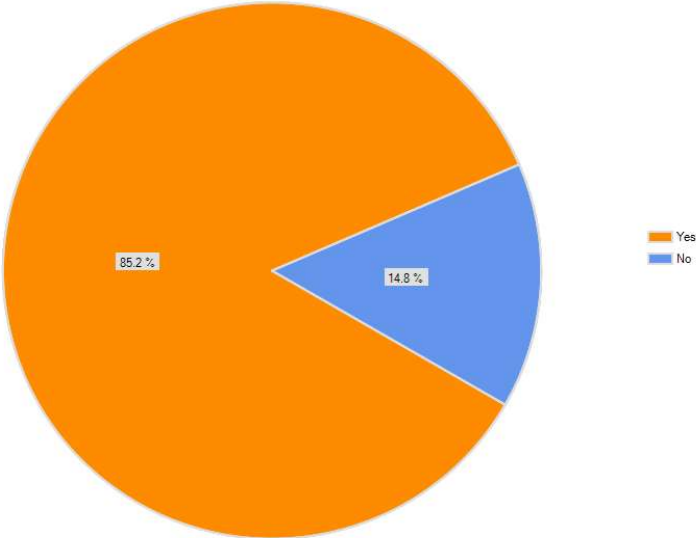


FIGURE 15: USING SOME FORM OF TESTING

What methods do you use for troubleshooting electric motor faults? (Check all that apply)

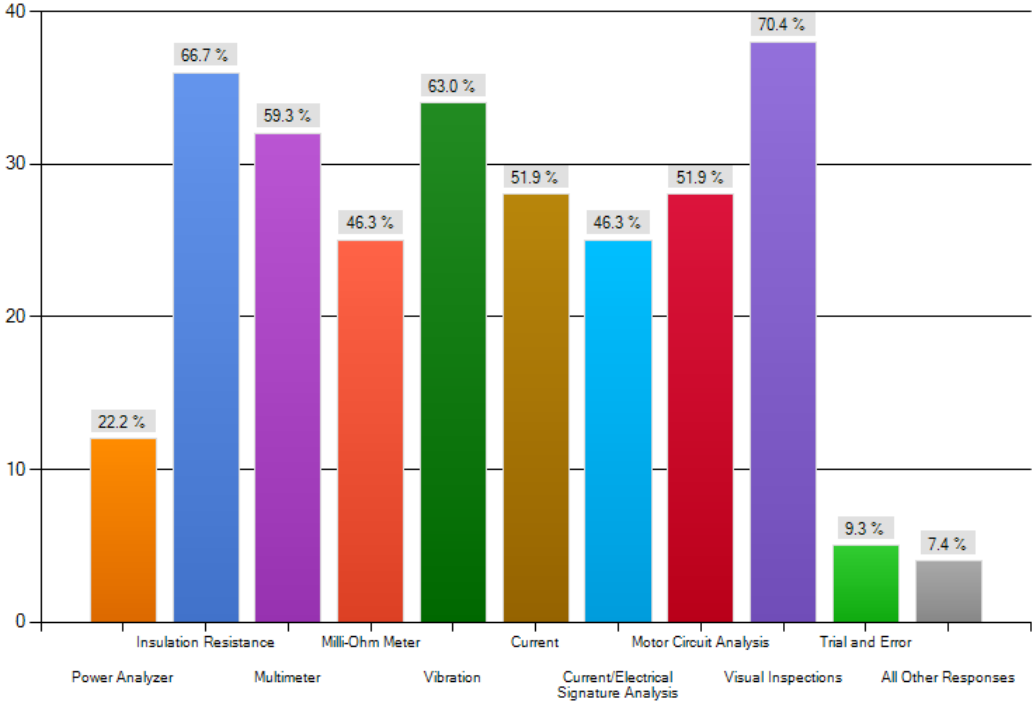


FIGURE 16: METHODS FOR TROUBLESHOOTING

2013 MDMH Study

In 2003, electricians were the primary group responsible for electric motor programs with reliability and PdM teams being a very small majority. In 2013, a significant trend is noted – Reliability and PdM managers result in a significant 44.4%. This trend, alone, is an important indicator of how companies are thinking in the area of equipment reliability.

In 2013, 66.7% of respondents reported having a reliability or PdM program in place for electric motors. This is about the same as the number that reported in 2003. However, from reviewing the data, it is apparent that companies are beginning to further define motor programs as more than just insulation resistance testing. This was a major issue in 2003, but, with the greater implementation of reliability and PdM programs within the companies, it is apparent that vibration, MCA, ESA/MCSA, and other technologies that will detect more issues are being used.

The average cost per hour downtime has not changed significantly since 2003 and remains an average per hour downtime cost of \$10,000.

The claimed plant operating profile has not changed since 2003 at 24/7 operations with the majority allowing only an annual planned shutdown.

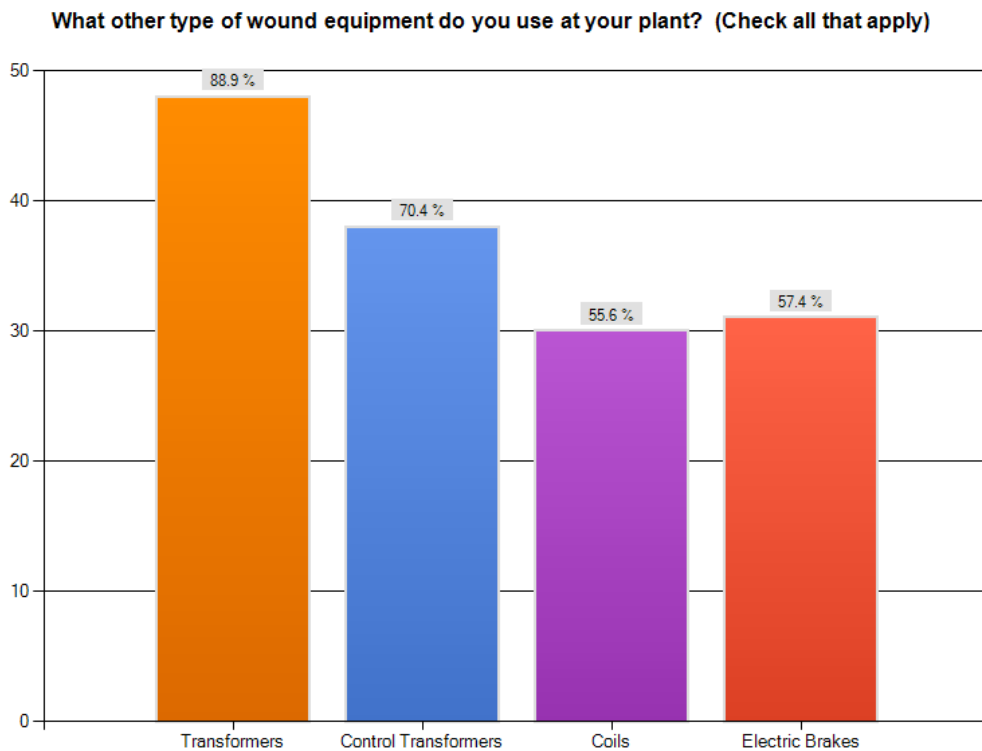


FIGURE 17: OTHER TYPES OF EQUIPMENT

Who is responsible for your electric motor programs?

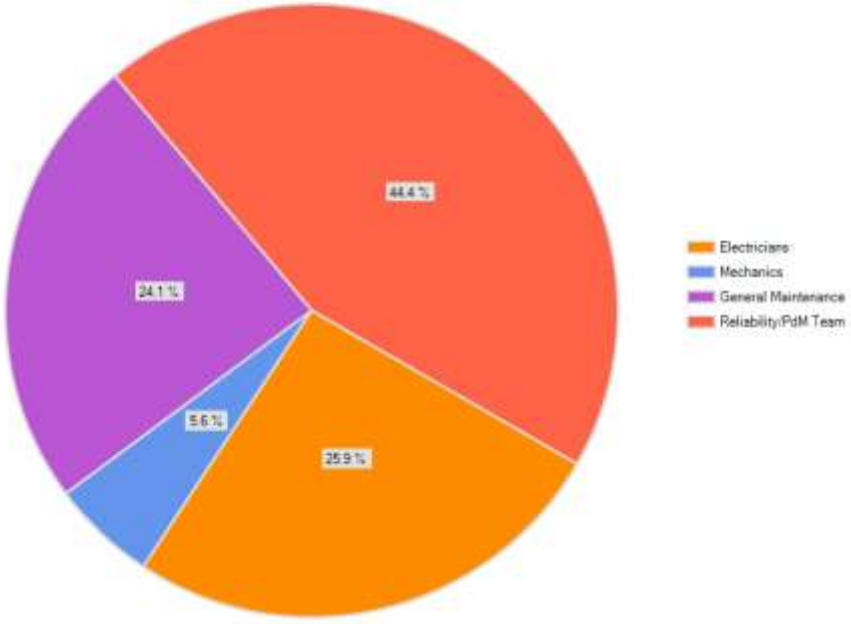


FIGURE 18: WHO IS RESPONSIBLE

Do you presently have a reliability or predictive maintenance program in place for your electric motors?

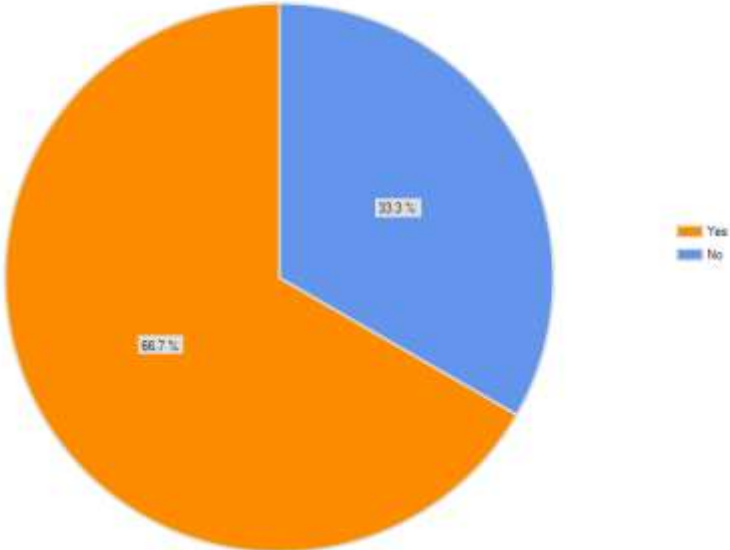


FIGURE 19: HAVE A RELIABILITY PROGRAM

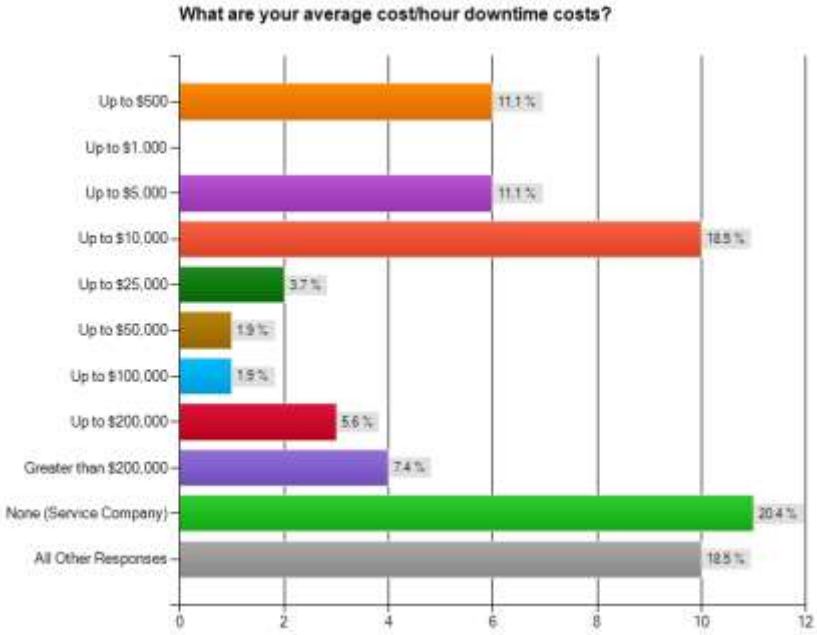


FIGURE 20: AVERAGE DOWNTIME COSTS

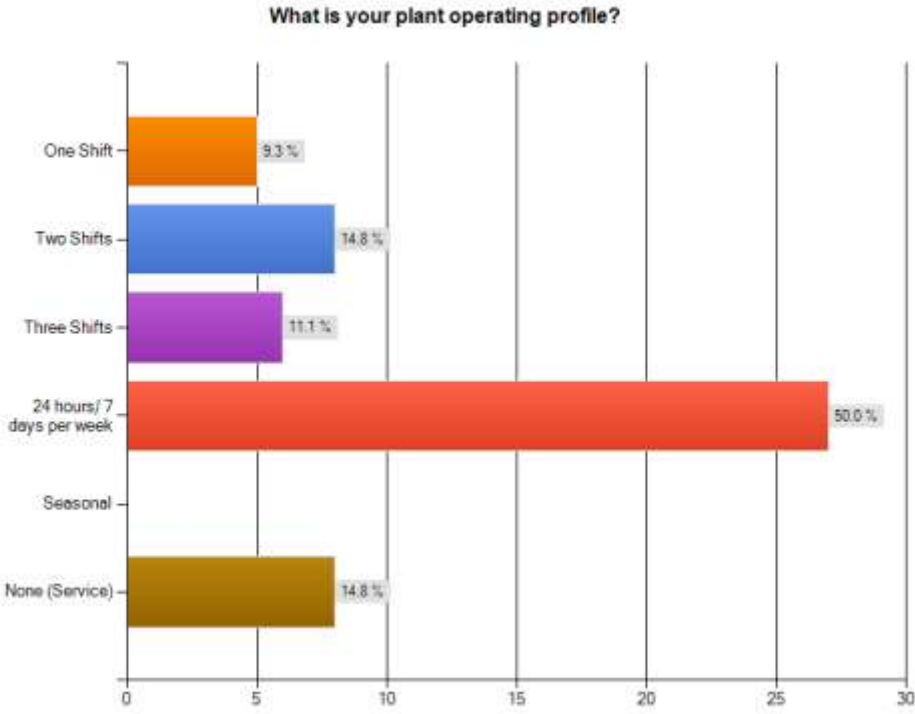


FIGURE 21: PLANT OPERATING PROFILE

By and large a majority feel that both online and offline testing combined will give the best return on investment.

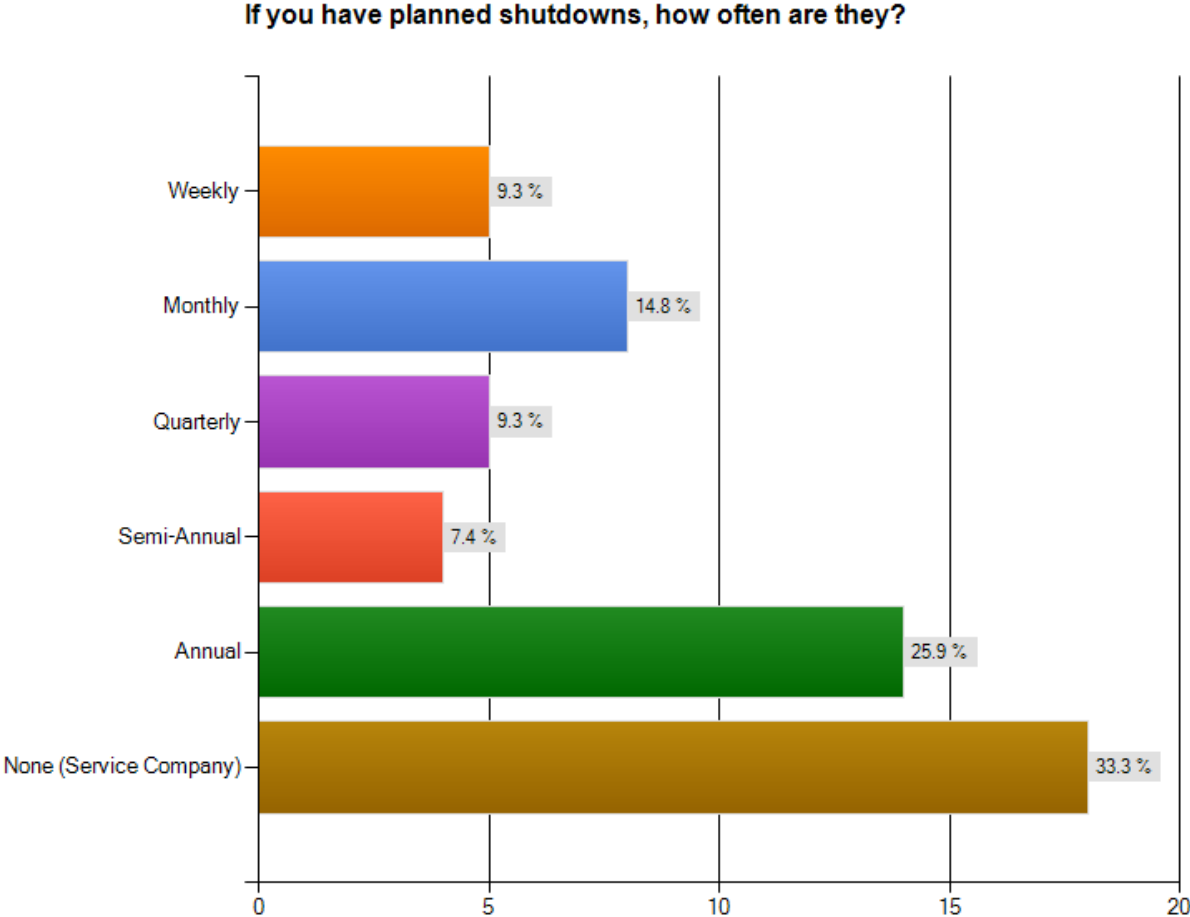


FIGURE 22: PLANNED SHUTDOWNS

TECHNOLOGY SPECIFIC

In this section we will be exploring several of the specific technologies and trade names. This data is derived from the survey and will explore the value that the users see in each one. We will also split the data into offline (MCA, which will include the SKF-Baker Advanced Winding Analyzer (AWA)) and online testing which encompasses both ESA/MCSA. In fact, all of the technologies covered online are Electrical Signature Analyzers (ESA) although often misnamed Motor Current Signature Analysis (MCSA) which primarily looks at the condition of the rotor. ESA technologies have the capability of looking at the complete incoming power, motor and driven equipment, in most cases.

The primary suppliers in the MCA market are (in alphabetical order): ALL-TEST Pro, Inc., which is a division of BJM Pumps, Inc., PdMA and SKF/Baker. ALL-TEST Pro has five off-line testers that are in use: ALL-TEST II; ALL-TEST Pro IV; ALL-TEST IV Pro 2000; ALL-TEST Pro 31; and, the ALL-TEST Pro 33. They also carry a version of the ALL-TEST Pro 33 meant for machine tool motors and hybrid vehicle motors. PdMA has two instruments the PdMA MCE (Motor Circuit Evaluation) and PdMA MCEmax, which is the same as the MCE but allows both the online and offline tests to be saved in the same database. The SKF/Baker is a special field version of the traditional insulation resistance, high potential test and surge comparison test with the exception that it has safeties built in that will protect the circuit if the instrument sees potential anomalies. This device is referred to as the Advanced Winding Analyzer (AWA) which comes in a variety of sizes based upon the output high potential and surge test capability.

In Figure 23, it can be determined that the majority of users are PdMA followed by ALL-TEST Pro and SKF/Baker. The most popular single instrument from the respondents is the ALL-TEST IV Pro 2000. In the additional responses, the SKF/Baker D12000 was included by one respondent. The other responses were rejected as they did not directly respond to the question nor mention other instruments.

It is important to note that these are not to be all-inclusive nor include permanently installed systems that are available on the market. For portable field instruments, these are the primary systems known to the marketplace. They are also 'combined' testers with specific combinations of testing performed. Individual insulation testing such as Tan Delta and other means are not included within the scope, but may be included in a future study.

What type of electrical diagnostic system do you feel fits your needs?

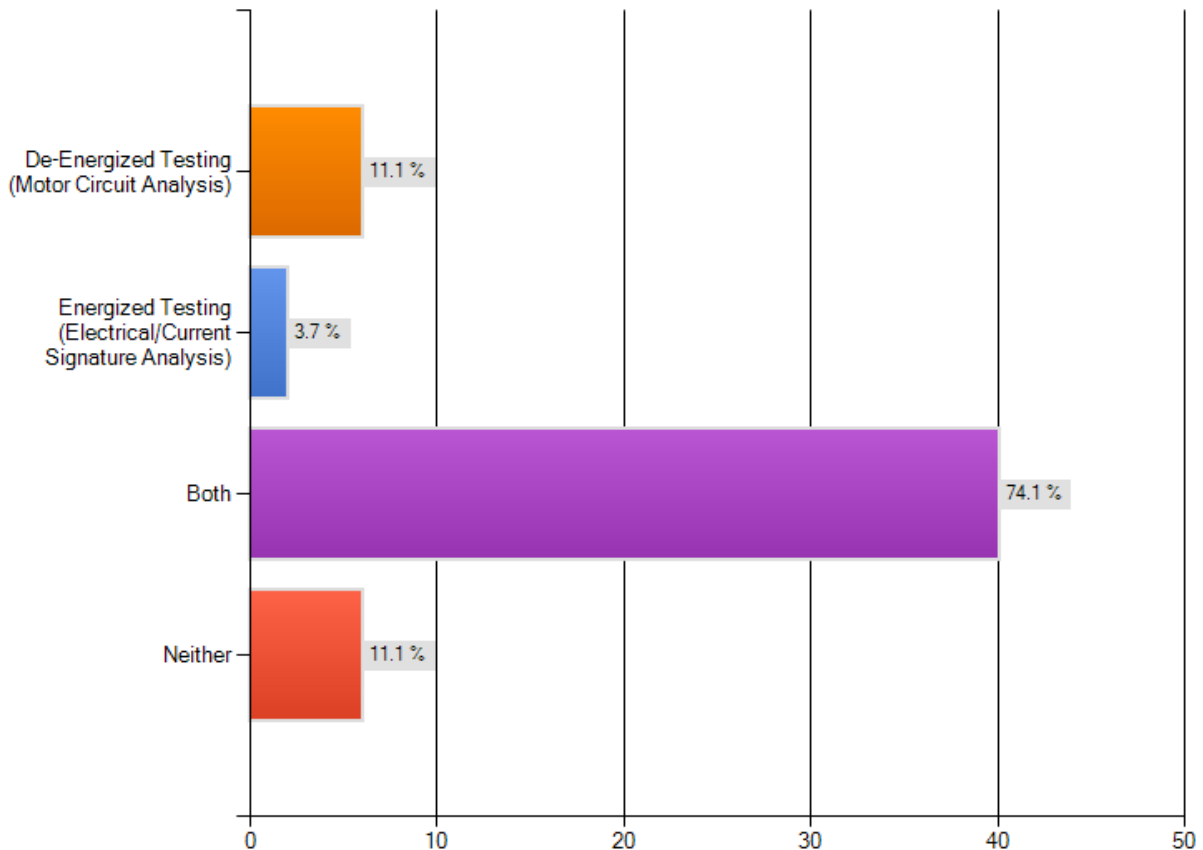


FIGURE 23: PROGRAM FIT

The primary ESA/MCSA devices reviewed in the study were the ALL-TEST Pro OL, the Areva EMPATH, the PdMA MCEmax, and the SKF/Baker Explorer. The one additional instrument included was a Siemens CMS4000, which is a permanently installed device outside the scope of this study. Also noted, but not mentioned by any respondents, are such technologies as Partial Discharge, EMI Testing, and others that are outside of the scope of this study but may be included in future studies.

As noted in Figure 24, the PdMA MCEmax (33.3%) and ALL-TEST Pro OL (16.7%) are the primary instruments of the respondents. The SKF/Baker Explorer and Areva EMPATH are included in the survey.

The majority of respondents found that MCA technologies are effective with a tendency towards finding most issues. In Table 3, we have identified how each of the MCA devices fall within the information from Figure 25.

2013 MDMH Study

Which Motor Circuit Analysis technology are you using? (Check all that apply)

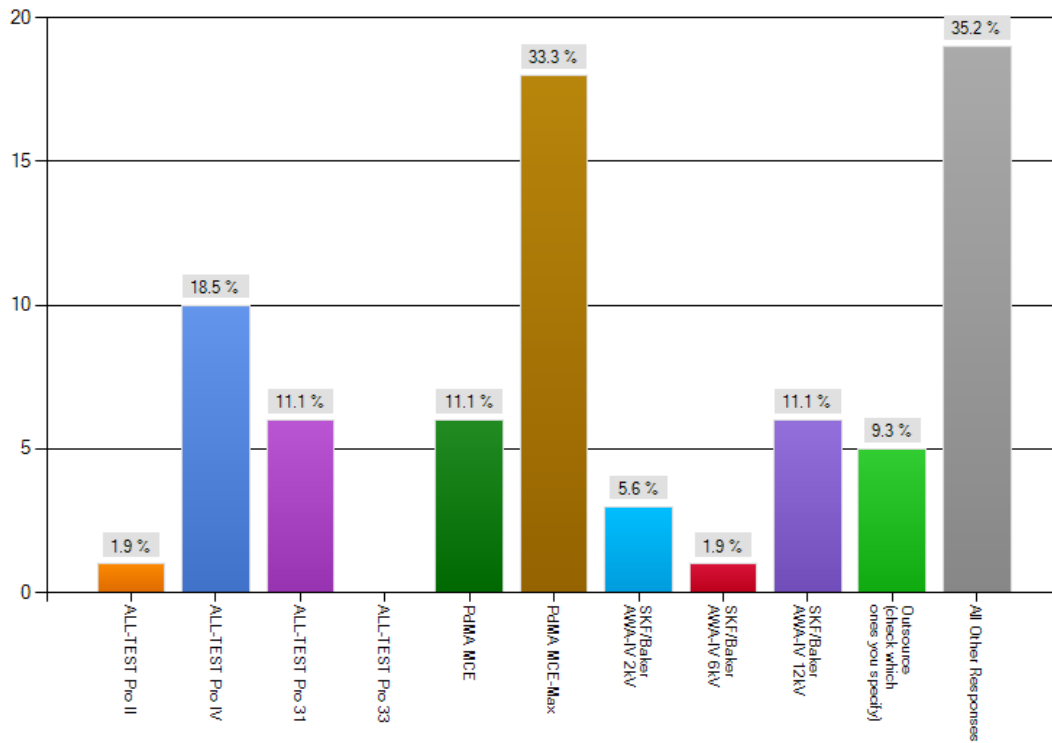


FIGURE 24: MCA BEING USED

TABLE 3: PERCEIVED EFFECTIVENESS OF MCA DEVICES (%)

Technology	Ineffective	Finds Some Issues	Average	Finds Most Issues	Completely Effective
ATPro II	-	-	-	100	-
ATPro IV	-	40	10	40	10
ATPro 31	-	33	17	50	-
ATPro 33	-	-	-	-	-
PdMA MCE	17	-	16	50	17
PdMA MCEmax	5.6	11.1	22.2	38.9	22.2
AWAIV 2kV	33	33	-	34	-
AWAIV 6kV	100	-	-	-	-
AWAIV 12kV	17	-	16	50	17

2013 MDMH Study

It was found that many of the users were using a combination of technologies, in particular, those that had a perception of greater effectiveness.

Which Electrical/Current Signature Analyzer(s) do you use? (Check all that apply)

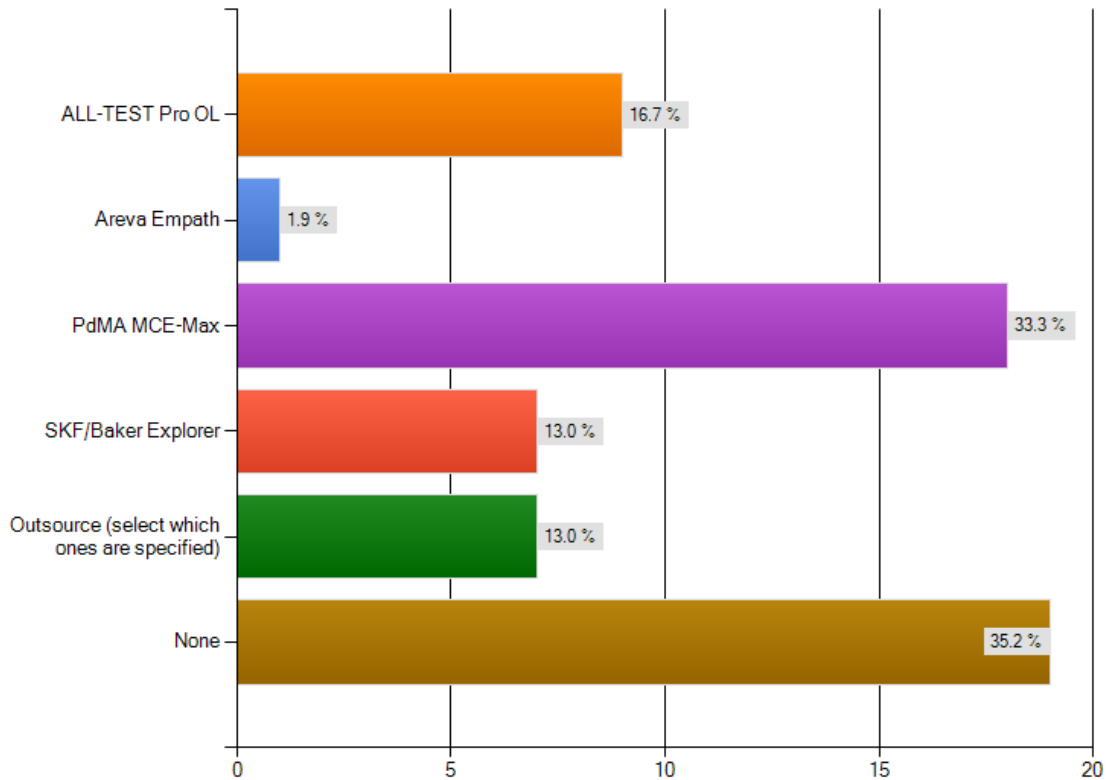


FIGURE 25: ESA/MCSA USED

Where MCA testing was found to tend towards effectiveness, ESA/MCSA results were found to tend towards average. The effectiveness of the technologies can be found in Table 4.

TABLE 4: PERCEIVED EFFECTIVENESS OF ESA/MCSA TECHNOLOGIES (%)

Technology	Ineffective	Finds Some Issues	Average	Finds Most Issues	Completely Effective
ATPOL	11.1	22.2	22.2	44.40%	-
EMPATH	-	-	-	100	-
MCEmax	11.1	16.7	22.2	38.9	11.1
Explorer	14.3	28.6	14.3	14.3	28.6

2013 MDMH Study

As with MCA, ESA/MCSA technologies appear to be most effective when used in combination with MCA and other ESA/MCSA technologies.

The primary uses determined by the respondents was a combination of winding fault detection and to be used for PdM. Rotor problems and testing before repair were the next issues for application.

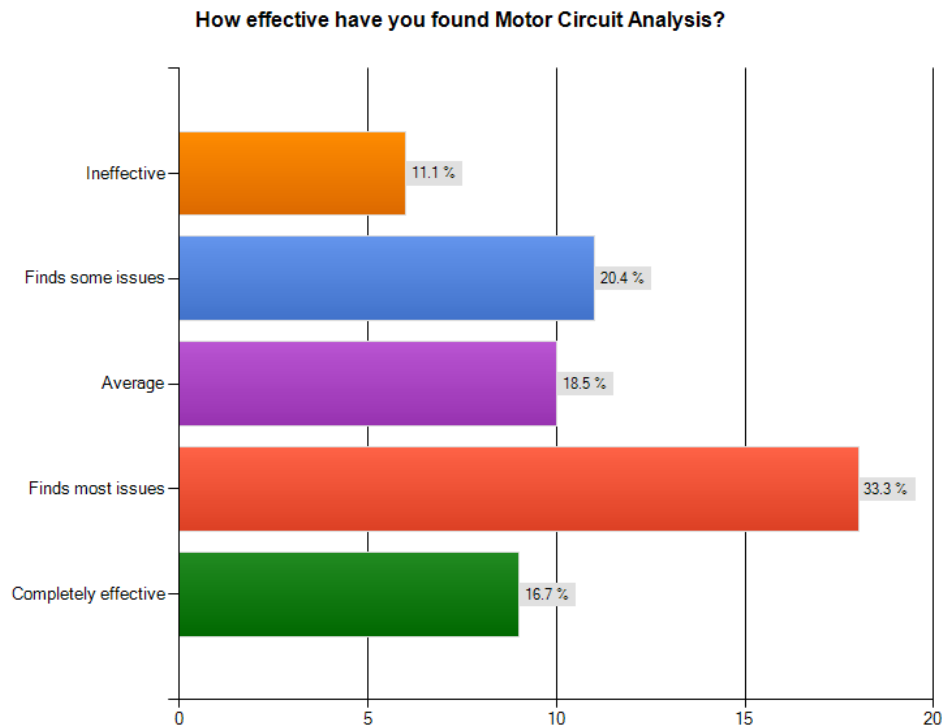


FIGURE 26: EFFECTIVENESS OF MCA

2013 MDMH Study

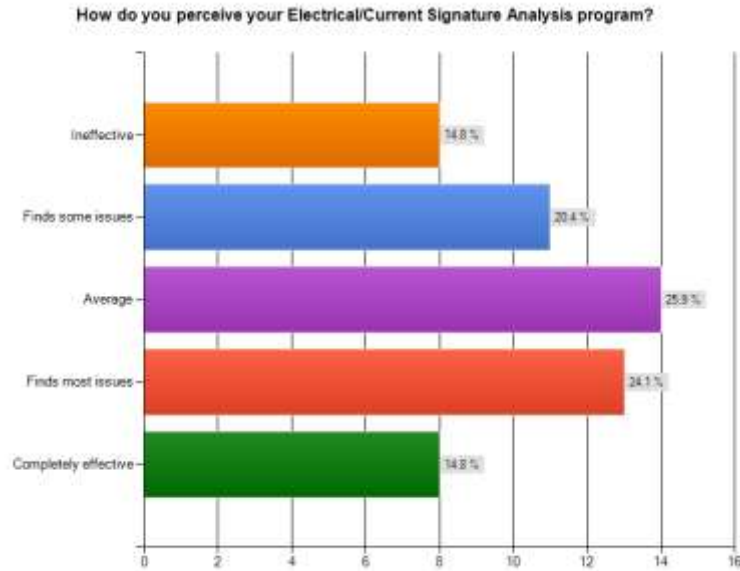


FIGURE 27: PERCEPTION OF ESA/MCSA

The perception of ESA/MCSA uses are primarily rotor and winding tests followed by PdM and motor mechanical faults.

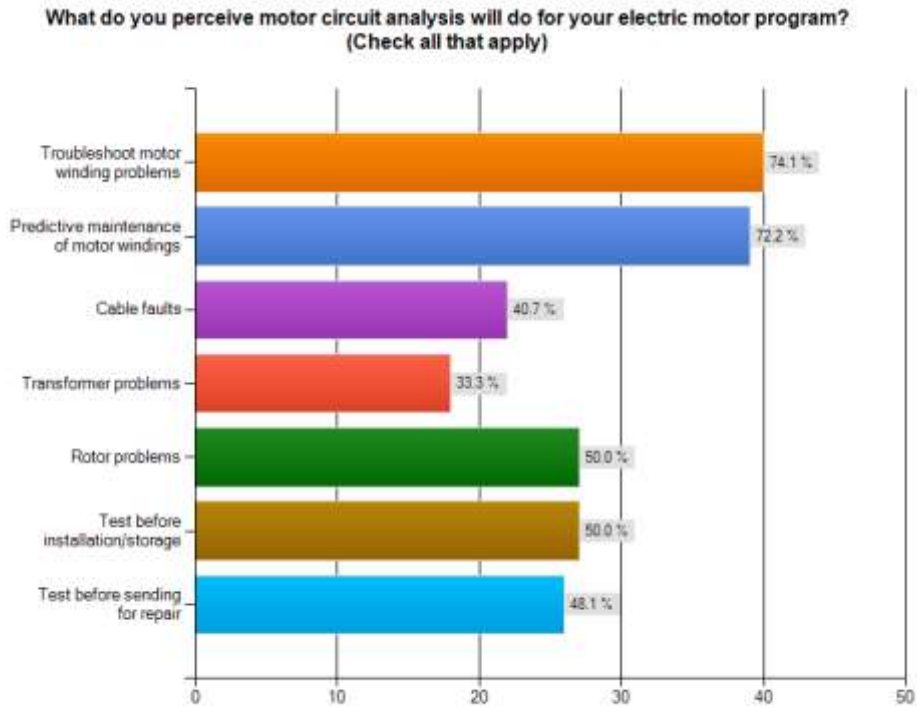


FIGURE 28: PERCEPTION OF MCA CAPABILITY

2013 MDMH Study

Only 9.3% of EMD users did not find an ROI. However, one of the respondents for no ROI is not a user of any of the technologies.

If you are using motor diagnostic technologies at your facility, has it met your expected Return on Investment?

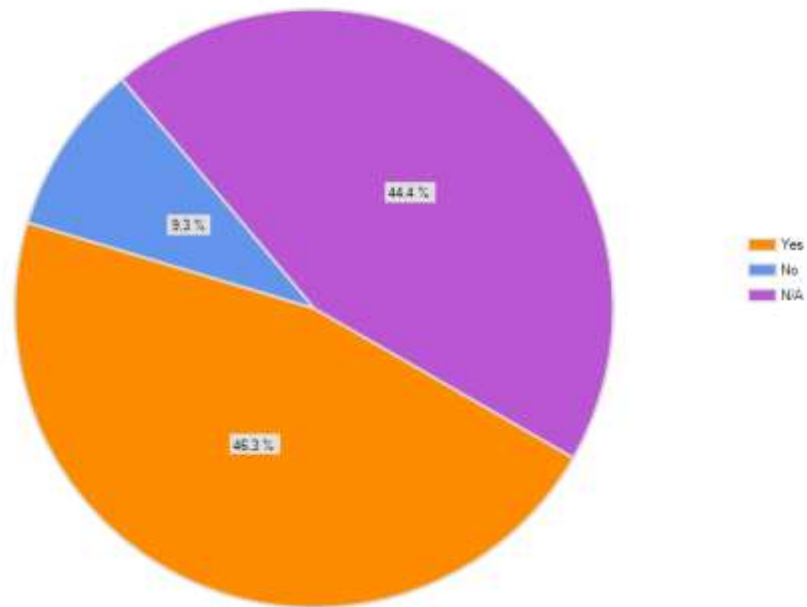


FIGURE 29: EMD ROI

75.5% of the respondents determined the primary driver for a motors program at the respondents' facilities. In 2003, the MDMH study found 3% interest in energy as a primary driver. The 2013 study found 0% interest in energy as a primary driver.

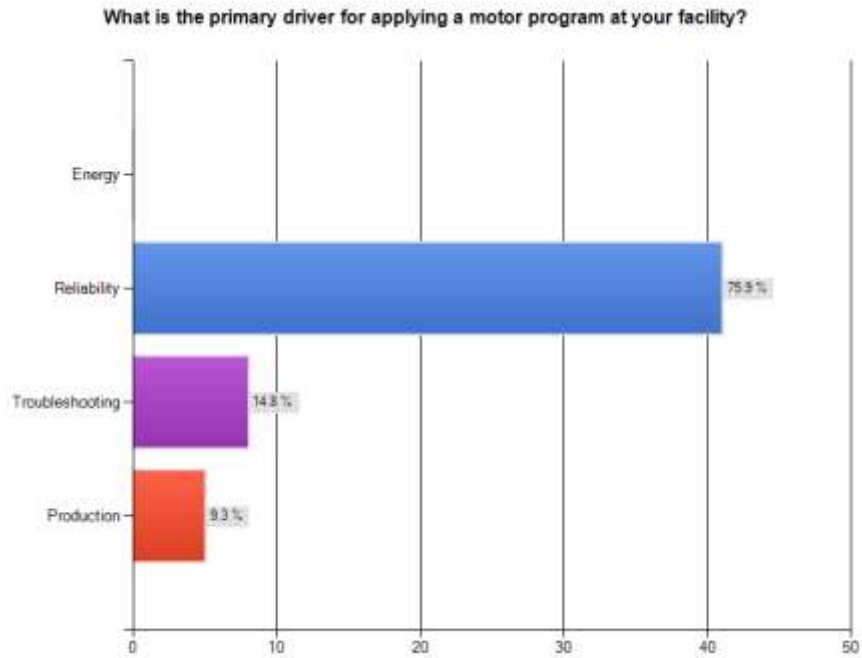


FIGURE 30: PRIMARY DRIVER FOR MOTOR PROGRAM

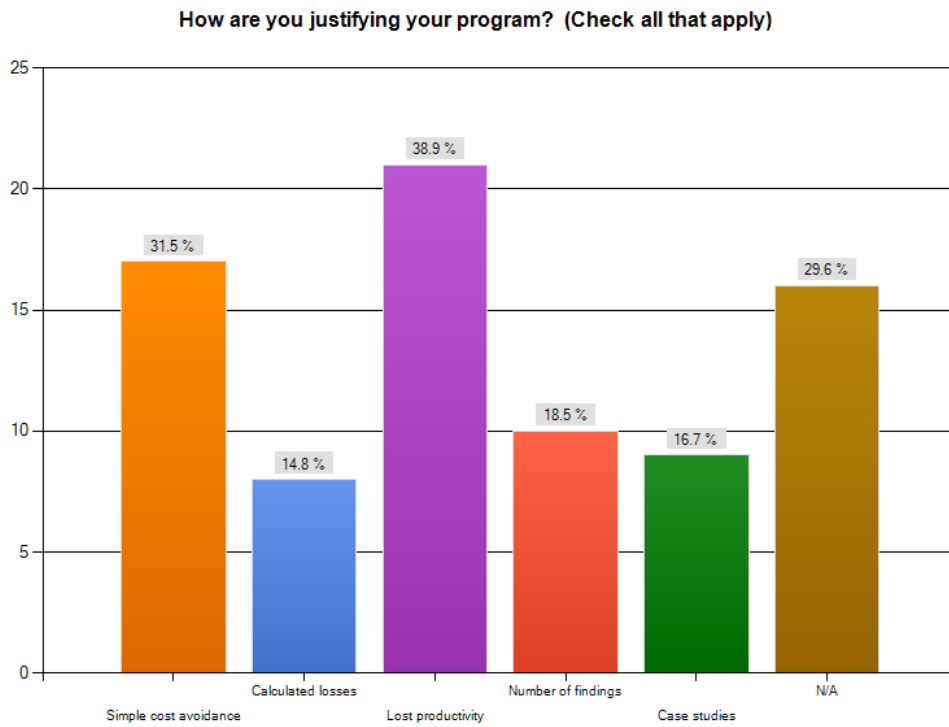


FIGURE 31: PROGRAM JUSTIFICATION

Surprisingly, each method shown above cannot be attributed to the perceived effectiveness of the program as the results are mixed for each. The most likely conclusion that can be made from this is that the individuals responsible for the program must learn the best method to communicate with decision-makers. None of the methods for justifying the program can be considered better than any of the others or ineffective.

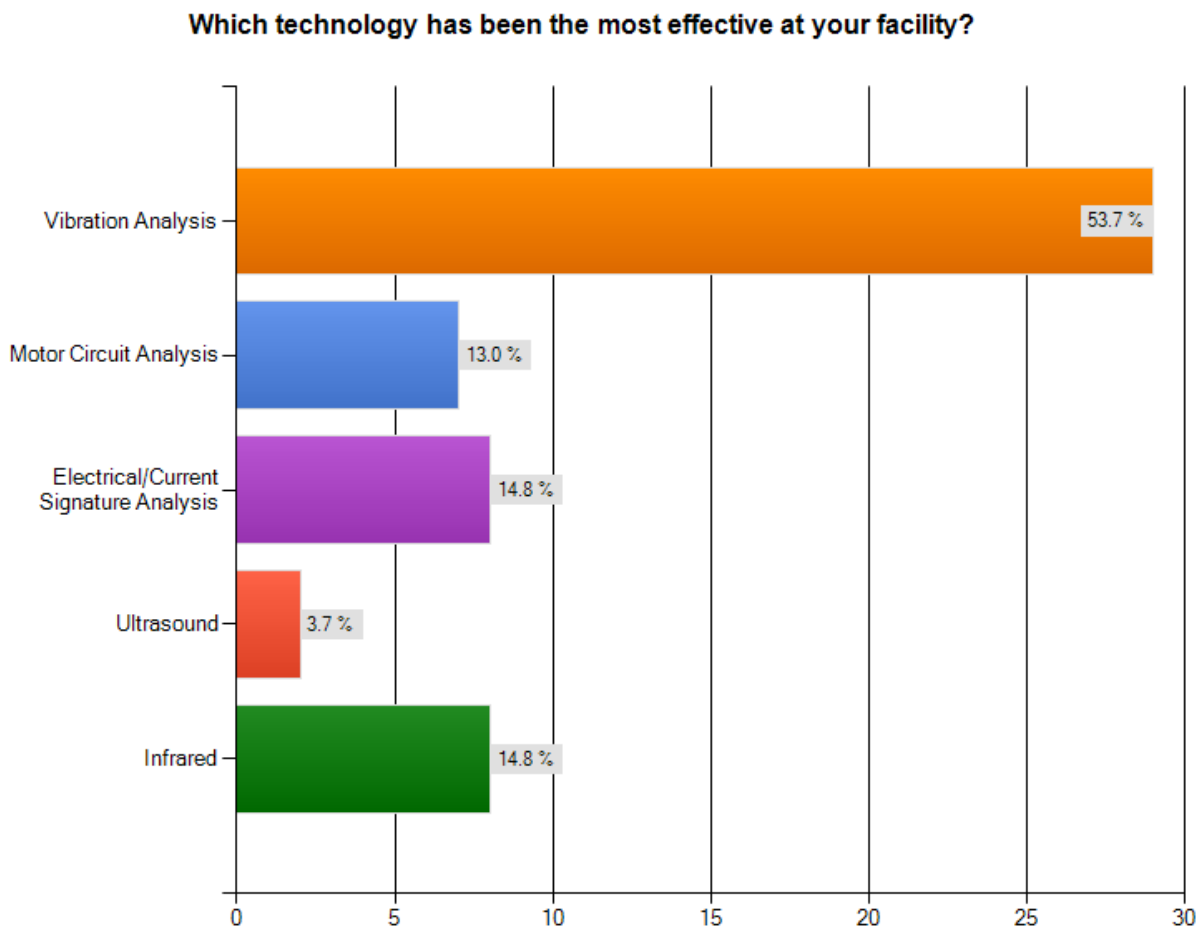


FIGURE 32: MOST EFFECTIVE PROGRAM

The most effective technology selected by the respondents for motor systems is vibration analysis.

CONCLUSION

It is only appropriate that the primary conclusion are the paraphrased advice from the technology users and motor managers.

- ⤴ Compare the costs of in-sourcing or out-sourcing motor management and diagnostics
- ⤴ Utilize dedicated and trained personnel
- ⤴ Promote significant findings
- ⤴ Allow at least a year for success following program implementation
- ⤴ Start small and grow the program (grass roots)
- ⤴ Have a successful motor storage program
- ⤴ Implement PdM programs
- ⤴ Ensure proper installation of motors, supply and driven equipment
- ⤴ Set good baselines
- ⤴ Work with stakeholders
- ⤴ Compare technologies before investing
- ⤴ Use for testing new and repaired electric motors
- ⤴ Compile critical motors and start there
- ⤴ Review repair versus replace programs and include replacement delivery times
- ⤴ Hire and train the right people and managers
- ⤴ Confirm finding to avoid improper calls
- ⤴ Utilize standards when available.

It was noted in the study that the important area of electric motor management, diagnostics and health is falling more and more under company reliability programs. From the potential costs associated with a failed program it makes sense that reliability engineers and a focus on machine reliability has become more of a focus.